OPAL: Network for the Detection of Stratospheric Change Ozone Profiler Assessment at Lauder, New Zealand.

I. Blind Intercomparison

I. S. McDermid [1], J. B. Bergwerff [2], G. Bodeker [3], I. S. Boyd [3], E. J. Brinksma [4], B. J. Connor [5,a], R. Farmer [6], M. R. Gross [7,b], P. Kimvilakani [8], W. A. Matthews[3], T. J. McGee [9], F. T. Ormel [4], A. Parrish [10], U. Singh [7,c], D. P. J. Swart [2], J. J. Tsou [11,d], P. H. Wang [12], and J. Zawodny [13].

1. Jet Propulsion Laboratory, California Institute of Technology, Table Mountain Facility, P. O. Box 367, Wrightwood, CA 92397-0367.
2. National Institute of Public Health and the Environment (RIVM), Air Research Laboratory, P. O. Box 1, 3720 BA Bilthoven, The Netherlands.
3. NIWA, Private Bag 50061, Omakau, Central Otago, New Zealand.
4. Vrije Universiteit, Faculty of Physics & Astronomy, De Boelelaan 1081, 1081 HV Amsterdam, The Netherlands.
5. NASA Langley Research Center, Hampton, VA 23681-0001.
6. ARC, 8201 Corporate Drive, Lanham, MD 20785.
7. Hughes STX Corporation, Lanham, MD 20706.
8. IDEA Corporation, Beltsville, MD 20705.
9. NASA Goddard Space Flight Center, Laboratory for Atmospheres, Code 916, Greenbelt, MD 20771.
10. University of Massachusetts, Physics and Astronomy Dept., Amherst, MA 01003, and Millitech Corporation, P. O. Box 109, South Deerfield, MA 01373.
11. Lockheed Engineering & Sciences Co., 144 Research Drive, Hampton, VA 23666.
12. Science and Technology Corporation, P. O. Box 7390, 101 Research Dive, Hampton, VA 23666-0390.
13. ASD-Aerosol Research Branch, MS 475, NASA Langley Research Center, Hampton, VA 23681.

a. Now at: NIWA, Private Bag 50061, Omakau, Central Otago, New Zealand.
b. Now at: ??
c. Now at: NASA Langley Research Center, MS 401B, Hampton, VA 23681
d. Now at: GATS, Inc., 28 Research Drive, Hampton, VA 23666.

Please address correspondence regarding this manuscript to I. S. McDermid, at the address above. Tel: (760) 249-4262. Fax: (760) 249-5392. E-mail: mcdermid@tmf.jpl.nasa.gov

Abstract

An intercomparison of ozone profiling instruments, two differential absorption lidars, a microwave radiometer, electrochemical concentration sondes, and the SAGE II satellite instrument is presented. The ground-based instruments were located at the Network for the Detection of Stratospheric Change (NDSC) primary station at Lauder, New Zealand. The campaign, which took place between April 15 and 29, 1995, strictly followed the NDSC guidelines for a blind intercomparison. Agreement between the measurements was within 15% for single profiles and within 10% for the campaign average, in the region from 20 to 40 km altitude. Outside of this region the differences were greater but can generally be ascribed to the limits of a particular instrument.

1. Introduction

The New Zealand National Institute of Water and Atmosphere (NIWA) atmospheric research station at Lauder (45.05°S, 169.68°E) has been designated as a primary site within the Network for the Detection of Stratospheric Change (NDSC). To fulfil this role, a variety of instruments have been installed at Lauder in order to make regular measurements of a number of important atmospheric species in accordance with the NDSC goal to make observations through which changes in the physical and chemical state of the stratosphere and upper troposphere can be determined and understood. In particular, the NDSC aims to make the earliest possible detection of changes in the ozone layer and to discern the cause of such changes.

Three different NDSC recognized instruments at Lauder are capable of ozone profile measurements: electrochemical concentration cell (ECC) balloon sondes, a UV differential absorption lidar (DIAL), and a 110-GHz microwave radiometer. The Ozone Profiler Assessment at Lauder (OPAL) was carried out from April 15 to 29, 1995 and one of the primary goals of the campaign was to evaluate the newly installed NDSC instruments, i.e., the RIVM DIAL system [*Swart et al.*, 1996] and the Millitech microwave radiometer [*Parrish et al.*, 1992, 1994]. The other instruments participating in this campaign were the balloon ECC sondes that were already part of the ongoing program at NIWA and the STROZ-LITE mobile DIAL system from the Goddard Space Flight Center (GSFC) [*McGee et al.*, 1991, 1995]. Additionally, results from several overpasses of the SAGE II satellite instrument, within 1000-km and 5° latitude, were included in the OPAL dataset.

The NDSC has developed a Validation Policy [*NDSC*] in order to ensure that the results submitted to its archives are of a known quality, as high as possible within the constraints of measurement technology and retrieval theory at the time the data were taken and analyzed. Blind instrument intercomparisons are an essential element of this policy and a specific format for these campaigns has been recommended by the NDSC-Steering Committee. One of the key elements of the Instrument Intercomparisons Protocol [*NDSC*] is that the campaign is under the control of an impartial referee who is responsible for handling all of the data and who has direct control of the campaign. This ensures, as far as possible, that the participants do not see each other's results during the campaign so that a true, blind intercomparison is achieved. The OPAL assessment of stratospheric ozone profile measuring instruments strictly followed the formal protocols for a NDSC blind intercomparison.

2. Instruments and Measurement Schedules

The instruments (with the exception of SAGE II) were all located at the Lauder site. This helped to minimize uncertainties in the intercomparisons due to spatial sampling but it should be recognized that the instruments all did observe somewhat different air volumes. Similarly, attempts were made to coordinate measurements at the same time, nominally local midnight. The long integration times employed by the lidars and the microwave radiometer helped to smooth out differences due to spatial and temporal sampling but this was not the case for the ozonesondes which made essentially instantaneous measurements at each altitude during the balloon ascent. Since the lidars could not operate simultaneously because of interference caused by light backscattered by the different laser beams the night was divided into four periods, two before midnight and two after, and the lidars were scheduled to run alternately during these periods. If the early lidar measurement appeared to be successful, determined primarily by the weather/cloud conditions, then an ozonesonde was launched as the next lidar measurement commenced.

By mutual consent of the investigators it was decided that the results would be compared as ozone number density as a function of geometrical altitude. This is the result produced directly by the lidars and SAGE II. The ozonesondes normally report ozone partial pressures but onboard measurements of temperature, pressure and humidity could be used to determine the ozone number density. The microwave radiometer normally retrieves ozone profiles as mixing ratio versus pressure and NMC (NCEP) data were used to make the conversion.

The local time at Lauder was 12 hours ahead of UT time; all dates and times given below refer to UT.

Differential Absorption Lidar – RIVM

The RIVM stratospheric ozone lidar [*Swart et al.*, 199*] was initially developed and tested in Bilthoven, The Netherlands, and was moved to Lauder in November 1994. The lidar follows the typical design of other stratospheric ozone DIAL systems using 308-nm pulses from a XeCl excimer laser as the 'on' wavelength and 353-nm pulses, generated by stimulated Raman shifting in hydrogen of a portion of the fundamental beam, as the reference, 'off' wavelength. To mitigate interference from aerosols the receiver incorporates channels at 332-nm and 385-nm for atmospheric N_2 Raman returns as well as the elastic channels at 308-nm and 353-nm. The system uses a single, untuned XeCl laser capable of producing an output power of 70 to 100-W at 250-Hz pulse repetition rate and the beams are expanded by a factor of 3.5 to reduce the divergence of the transmitted light. A 0.8-m diameter Newtonian telescope is used to collect the backscattered laser radiation and a high speed chopper helps to reduce the signal-induced-noise effects caused by intense low altitude echoes. Dichroic band mirrors eliminate visible radiation and dichroic long-wave pass mirrors separate the four detected wavelengths. Interference filters further spectrally purify these four wavelength channels. The signal is then measured using photomultipliers and photon counting techniques.

Run #	Day	Date	Start Time	End Time		Comments
1	1	4/15/95	8:55	10:00		
2	1	4/15/95	12:28	14:00	φ	
3	2	4/16/95	10:05	10:30		Cut short by clouds
4	3	4/17/95	7:50	9:00		
5	3	4/17/95	11:44	13:00		
6	6	4/20/95	15:12	17:50	φ	
7	7	4/21/95	10:00	-		Suspended several times for clouds
8	8	4/22/95	9:30	10:00		
9	8	4/22/95	14:45	17:25	φ	
10	9	4/23/95	14:16	16:10	φ	
11	11	4/25/95	7:55	10:35	φ	
12	12	4/26/95	9:45	11:19	φ	
13	14	4/28/95	12:12	14:12	φ	
14	15	4/29/95	12:07	12:25		
φ Different altitude sections of this profile were recorded at different times during this period.						

Table 1. Dates and times (UT) of the RIVM lidar observations.

Table 1 shows the dates and times that ozone profiles were obtained by the RIVM lidar during OPAL. During this period the RIVM group experimented with different methods of acquiring data. The final ozone profile is normally made up of three separate profiles, i.e., Raman, low altitude/intensity, and high altitude/intensity. For some experiments these profiles were acquired simultaneously with the optical chopper at a single fixed altitude, nominally 12-km. In the alternate method, used where indicated by φ in table 1, the effective altitude of the chopper opening time was changed between 6-km, 12-km and 25-km, and segments of these separate measurements were then combined to produce the complete profile.

Microwave Radiometer – LaRC/Millitech

The Millitech Corporation have developed a design for a largely automated microwave radiometer for long-term ozone monitoring [*Parrish et al.*, 1992; *Parrish, 1994*]. Two nearly identical units were built and are in long-term operation at NDSC stations. The unit normally operating at Lauder and used in this campaign previously participated in the STOIC intercomparison campaign [*Connor et al.*, 1995; *Margitan et al.*, 1995] and a long-term intercomparison with SAGE-II and with the ozone DIAL at the JPL Table Mountain Facility in California [*Tsou et al.*, 1995].

The instrument observes the microwave emission from atmospheric ozone at 110.836 GHz (λ=2.6 mm) [*Parrish et al.*, 1992]. It principally consists of a millimeter wave receiver and a multichannel spectrometer. The receiver converts microwave signals at its input to lower intermediate frequencies (IF) by heterodyning them with a local oscillator. The IF output of the receiver is then processed by a multichannel filter spectrometer followed by detectors and digitizer circuits. The ozone altitude distribution is determined from the details of the pressure-broadened line shape through a method based on the optimal estimation technique of *Rodgers* [1976].

Run #	Day	Date	Start Time	End Time	Day/Night
1	1	4/15/95	7:44	16:34	Night
2	2	4/16/95	7:44	10:08	Night
3	3	4/17/95	7:31	17:53	Night
4	4	4/18/95	1:07	5:41	Day
5	5	4/19/95	19:41	21:13	Day
6	6	4/20/95	13:59	17:55	Night
7	7	4/21/95	8:17	13:45	Night
8	8	4/22/95	12:14	18:03	Night
9	9	4/23/95	7:18	17:46	Night
10	10	4/24/95	0:09	5:18	Day
11	13	4/27/95	21:51	23:58	Day
12	14	4/28/95	10:00	17:18	Night
13	15	4/29/95	7:13	17:59	Night

Table 2. Dates and times (UT) of microwave ozone profile measurements.

The microwave radiometer made continuous measurements throughout the OPAL campaign period, as indicated in table 2. The profiles were separated into two groups defined by the integration period, either daytime or nighttime. In accordance with the goal to obtain temporal coincidence between the measurements the nighttime measurements were preferred. On some days the weather conditions prevented nighttime observations and on these occasions the daytime results were included in the OPAL dataset. This generally does not cause a problem for the intercomparisons since on the occasions when the weather precluded nighttime microwave measurements there were also no lidar or ozonesonde observations.

Electrochemical Concentration Cell Ozonesondes – NIWA

The ECC ozonesonde [*Komhyr*, 1969; *Komhyr and Harris*, 1971] is a compact, lightweight, balloon-borne instrument that is capable of measuring the ozone profile from the surface up to the burst altitude of the balloon which is normally <35 km using rubber balloons. The ozonesonde is coupled with a standard meteorological radiosonde for data telemetry and simultaneous measurement of meteorological parameters. The sensor is based on an iodine-iodide redox concentration cell which generates an electric current when air containing ozone is pumped through it. It contains two bright-platinum electrodes immersed in potassium iodide (KI) solutions of different concentrations, contained in separate anode and cathode chambers linked with an ion bridge. Air is forced through the sensor by a non-reactive (Teflon) pump. These pumps must be carefully calibrated since it is essential to know the rate and volume of the air sampling to obtain an accurate ozone measurement. Ozone in the air reacts with the aqueous KI solution to form iodine (I_2). The cell then converts the I_2 back to iodide and two electrons flow in the sensor circuit for each ozone molecule. The sensor current is therefore directly related to the ozone partial pressure.

Sonde	Day	Date	Start Time	End Time	Max. Alt. (km)
396	1	4/15/95	12:51	13:35	12.0
397	2	4/16/95	9:57	11:55	34.2
398	3	4/17/95	9:31	11:19	33.7
399	6	4/20/95	12:28	14:13	34.8
400	7	4/21/95	10:11	12:07	34.8
401	8	4/22/95	11:07	13:10	35.4
402	9	4/23/95	12:18	14:03	32.4
403	11	4/25/95	9:17	11:04	34.1
404	12	4/26/95	22:31	0:43	35.0

Table 3. Dates, times (UT) and maximum altitudes for the NIWA ozonesondes.

Ozonesondes have been launched weekly at NIWA-Lauder since 1985. During the OPAL campaign 9 ECC sondes, series 1Z, were launched as indicated in table 3. An additional ozonesonde, launched on April 29, did not function correctly and was therefore not included in the OPAL dataset.

Mobile Differential Absorption Lidar – GSFC

The Goddard Space Flight Center mobile lidar has been described in detail in the literature [*McGee et al.*, 1991, 1993, 1995]. The transmitter consists of two excimer lasers, a XeCl laser emitting at 308 nm, which is absorbed by ozone, and a XeF laser, emitting at 351 nm, which is used as an atmospheric reference. The lasers operate at 200Hz and are fired asynchronously so as to avoid optical crosstalk in the receiver. The timing of each laser is controlled by a dedicated mechanical chopper. The choppers protect each of the high sensitivity, elastic backscatter channels from the intense burst of light from scattering at low altitudes.

Wavelength separation in the receiver is achieved using beamsplitters and narrow band interference filters. Four different wavelengths are collected; the elastically backscattered signal from each of the transmitted laser beams (308 and 351 nm), and the Raman shifted wavelengths from scattering by atmospheric nitrogen for each transmitted laser beam (332 and 382 nm). The Raman shifted wavelengths provide aerosol information and can be used to retrieve ozone in the presence of heavy aerosol loadings [*McGee et al.*, 1993]. Each unshifted, elastically scattered signal is split into two detectors with differing sensitivities. This is done to increase the dynamic range of the instrument. The receiver thus consists of six detectors.

Run #	Day	Date	Start Time	Integration Time	Comments
1	1	4/15/95	10:54	1:23	
2	1	4/15/95	14:12	1:23	
3	2	4/16/95	7:58	1:23	
4	3	4/17/95	10:04	1:23	
5	3	4/17/95	13:05	1:23	
6	5	4/19/95	8:44	1:23	
7	6	4/20/95	13:10	1:23	
8	7	4/21/95	8:20	1:23	
9	7	4/21/95	11:35	1:21	Poor Conditions
10	8	4/22/95	12:30	1:30	
11	9	4/23/95	12:01	1:30	
12	11	4/25/95	11:05	1:23	
13	12	4/26/95	7:12	1:23	
14	14	4/28/95	10:25	1:42	
15	15	4/29/95	7:50	2:05	

Table 4. Dates and times (UT) of the GSFC lidar observations.

The signals from the six photomultiplier tubes are amplified and discriminated and the resulting pulses are counted using fast multichannel scalers (MCS). Data is collected in one microsecond bins, corresponding to a vertical resolution of 150 meters, for 1.2 milliseconds after each laser pulse. Data from consecutive laser shots are summed on the MCS boards, and written to a file after 50,000 shots are accumulated (roughly 4.5 minutes). Data are acquired until a million laser pulses have been summed. The speed of the data system is now determined by the rise time of the PMT's in use and all the electronics now have a bandwidth of 300 MHz. Data acquisition is controlled using LabVIEW routines run on a dedicated PC. GSFC lidar observations during OPAL are summarized in table 4.

SAGE II

The SAGE II (Stratospheric Aerosol and Gas Experiment) [*McCormick et al.*, 1989] instrument is a seven-channel, limb-scanning sun photometer using the solar occultation technique and was launched onboard the ERBS (Earth Radiation Budget Satellite) in October 1984. Ozone concentrations are inferred from the 0.6 μm radiances with a precision of ~5% in the stratosphere for a vertical correlation distance of 3 km. The latitude range extensively sampled extends from 65°S to 65°N with a roughly one month repeat cycle. The measurements at a particular latitude are grouped over several days. During the OPAL campaign there were 10 SAGE II overpasses where the measurement tangent point was within 1000 km of the Lauder site. However, only 4 of these, listed in table 5, met the additional criterion of being within 5° latitude of Lauder. The SAGE II results were not truly part of the blind intercomparison but the observations were processed in the routine manner using the SAGE II operational software and were not influenced in any way by the results obtained by the NDSC instruments.

Day	Date	Time	Latitude	Longitude	Distance	SR/SS
4	4/18/95	6:23	-41.7°	164.6°	568 km	Sunset
5	4/19/95	6:29	-44.8°	161.6°	659 km	Sunset
6	4/20/95	6:34	-47.3°	158.7°	905 km	Sunset
7	4/21/95	5:03	-49.2°	179.9°	898 km	Sunset

Table 5. Dates, times (UT) and tangent point locations for SAGE II overpasses within 1000 km and ±5° latitude of Lauder (45.1°S, 169.7°E).

3. Ozone Profile Intercomparisons

During the 15 day period of the campaign the individual investigators turned in their results to the referee, usually within 48 hours of the observation, following their standard data analysis procedures. These results were held by the referee and no investigator saw the results from any other instrument until the end of the campaign period. The final blind dataset was completed and sealed two days after the last observations.

Day	Date	GL-GSFC	MM-LaRC	NZ-NIWA	RL-RIVM	SA-SAGE II
1	4/15/95	✓ ✓	✓	✓	✓ ✓	
2	4/16/95	✓	✓	✓	✓	
3	4/17/95	✓ ✓	✓	✓	✓ ✓	
4	4/18/95		✓			✓
5	4/19/95	✓	✓			✓
6	4/20/95	✓	✓	✓	✓	✓
7	4/21/95	✓ ✓	✓	✓	✓	✓
8	4/22/95	✓	✓	✓	✓ ✓	
9	4/23/95	✓	✓	✓	✓	
10	4/24/95		✓			
11	4/25/95	✓		✓	✓	
12	4/26/95	✓		✓	✓	
13	4/27/95		✓			
14	4/28/95	✓	✓		✓	
15	4/29/95	✓	✓		✓	

Table 6. Summary of all profiles submitted to the OPAL Blind Database

To simplify entries in tables and chart legends, a two-letter code was assigned to each instrument: GL = GSFC Lidar, MM = Millitech Microwave, NZ = NIWA ECC sondes, RL = RIVM Lidar, and SA = SAGE II. Table 6 summarizes the results available in the OPAL dataset. There are seven days when all of the instruments located at Lauder obtained measurements but only on 2 of these days did SAGE II also have a nearby profile.

The various instruments all have different vertical resolution and report ozone values at different altitudes. For some instruments the altitude resolution can vary depending on the experimental conditions, as can the maximum and minimum altitudes of the measured profiles. Typical altitude resolutions and altitude ranges of individual measurements during OPAL are shown in plate 1. To enable the intercomparisons to be made, a cubic spline interpolation of the individual profiles was applied to provide data points at 0.5 km intervals. No attempt was made to convolve the vertical resolution to any fixed value and there could therefore be some minor issues in the intercomparisons associated with under-sampling some profiles, e.g., ECC, and over-sampling others, e.g., microwave.

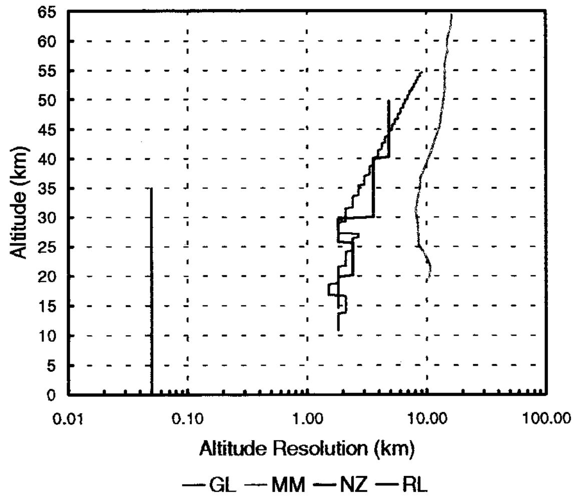

Plate 1. Typical altitude resolution and operating range for the Lauder NDSC instruments. These values may vary slightly between observations, particularly for the RIVM lidar (RL) and the NIWA ozonesondes (NZ) (Note logarithmic altitude resolution scale).

Each instrument team also provided precision estimates for the reported ozone concentrations. These values can vary depending on the experimental conditions but typical errors reported for individual profiles during OPAL are shown in plate 2. It should be noted that these error estimates are those given by the individual investigators and do not result from any critical assessment as part of the OPAL campaign.

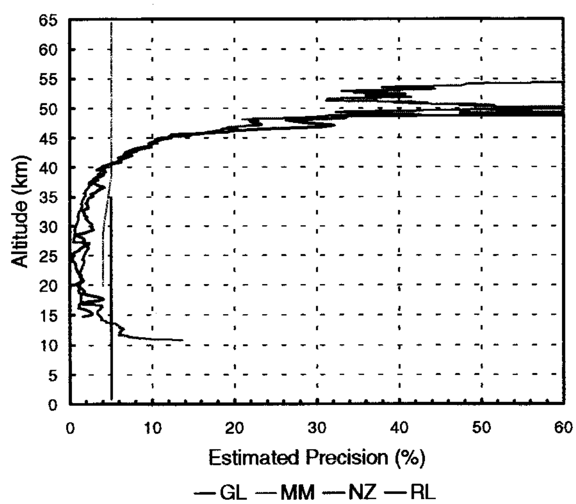

Plate 2. Ozone concentration precision estimates as a function of altitude.

Campaign Average Profiles

The average of all the measurements indicated in table 6 for each instrument provides a single mean profile for each instrument and these profiles were compared first. This average should provide the smoothest profiles for comparison since most of the small scale variability, both day-to-day and spatial, will be filtered out by the averaging. These profiles, from the blind part of the campaign, are shown in plate 3.

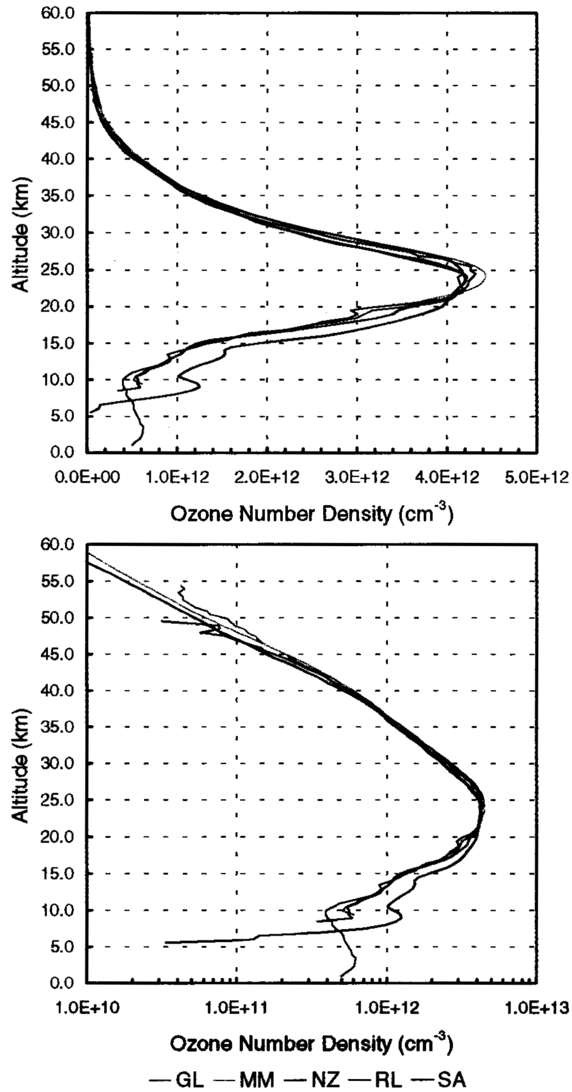

Plate 3. Blind results: Ozone profiles averaged over the entire OPAL campaign period for each instrument.

The profiles are plotted on both a linear and a logarithmic ozone concentration scale to exemplify the differences in the measurements in different altitude regions. The differences at the upper altitude range of the profile are more clearly seen in the log-plot and those near the ozone maximum are better observed in the linear plot. Some differences can be seen between the ozone profiles in plate 3, especially for SAGE II below 20 km, but for the altitude range from approximately 10 to 45 km there is a broad agreement between the instruments at Lauder.

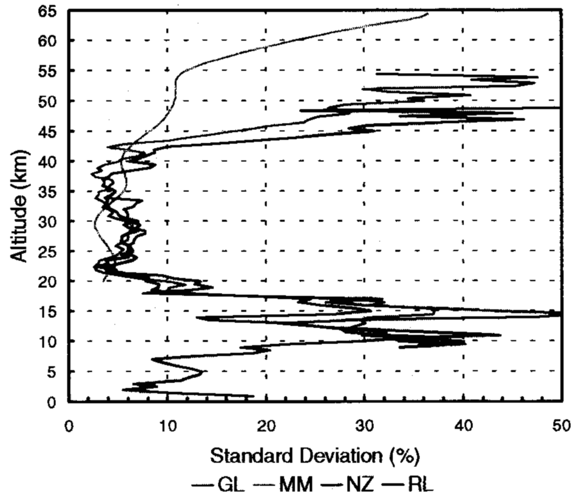

Plate 4. Standard deviation of all OPAL blind profiles for each instrument.

Plate 4 shows the standard deviations (1-sigma) of all the profiles recorded by each instrument during OPAL and contributing to the mean profiles shown above. These standard deviations contain both the natural atmospheric variability and the variability (precision) of each measurement technique. Comparing this plate with the precision estimates in plate 2 we might deduce that there was little atmospheric or instrument variability between 20 and 42 km. Below 20 km there appears to be significant atmospheric variability since the standard deviations of the measurements are very much greater than the precision estimates in this region. Above 42 km the deviations seem to be due primarily to the deterioration of the lidar signals at the upper limit of their measurement range. Above ~50 km there are natural diurnal variations in the ozone concentration which will be observed by the microwave instrument since it makes both daytime and nighttime measurements.

It can simplify the presentation if the profiles measured by the different instruments can be individually compared to some reference profile. In STOIC [*Margitan et al.*, 1995], for example, a reference profile was created by averaging together all the measurements made by all of the instruments during the campaign. However, for OPAL it was decided that there were not sufficient independent measurements that this might not cause undue bias. A climatological profile was obtained by averaging all SAGE measurements made within 1000 km and 5° latitude of Lauder during the years 1985-1991 (pre-Pinatubo). Plate 5 shows the difference between the average of the profiles measured by each instrument during the OPAL campaign and this SAGE II climatology. The agreement between the Lauder instruments and the SAGE II climatological profile is better than 10% between 20 and 45 km. Below 15-20 km the actual mean ozone profile during the OPAL campaign appears to be quite different to the climatological profile although the Lauder instruments continue to agree within 10% of each other in this range and they all show a similar difference to the climatology.

Above 45 km there are clearly other problems than the climatology simply not being representative as there is essentially no agreement between any of the measurements in this altitude region. It is also clear from this plate that the ozone profile sampled by SAGE II is different from that observed by the instruments at Lauder, especially below 20 km altitude, and is also significantly different to the SAGE II climatology for the same geographical region. Since the agreement between the instruments is much better than the agreement with the SAGE II climatology it would appear that this may not the best profile to use as a reference and that it would be better to calculate and graph the differences between each individual instrument profile and the other four (potential) profiles.

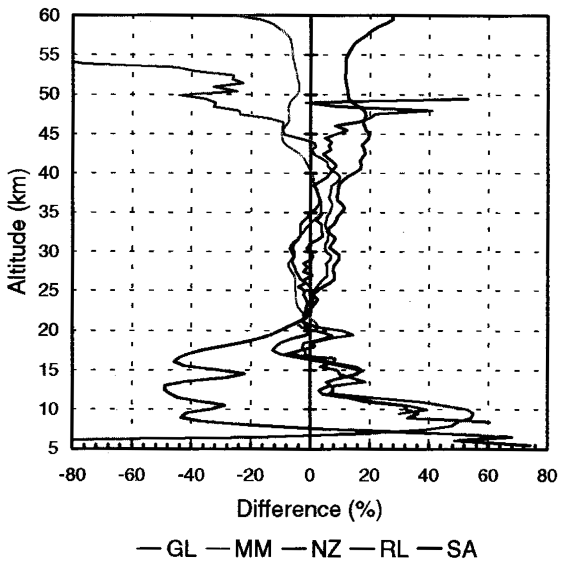

Plate 5. Difference between the SAGE II climatological profile and the OPAL mean profile for each instrument.

Plates 6(a)-(d) show the difference of the OPAL blind average profile for each individual instrument compared with that from each of the other instruments. There is an interesting node point at approximately 22 km in all of these plates where the instruments agree perfectly but there is no obvious explanation for this. Except for the differences with the SAGE II profile below 20 km there are no strong biases for any instrument and it is assumed that the SAGE II measurements, almost 1000 km distant from Lauder, sample a totally different airmass in this altitude region. The best agreement among all of the instruments is between 20 and 40 km where the differences are all within 15% and generally less than 10%. The microwave radiometer appears consistently to produce slightly higher ozone values than the other instruments between 20 and 45 km although the agreement with the RIVM lidar between 20 and 40 km is better than 7%. In this same region the SAGE II and GSFC lidar differences do not exceed 4%. At about 40 km for RIVM and 45 km for GSFC the lidar errors start to increase rapidly and the differences, compared to the microwave, are more than 30% at 50 km. The two lidars agree within 12% from the bottom of their profiles near 10 km up to approximately 45 km. The ECC sonde measurements fit well with the other instruments in the 20 to 35 km region. Below 20 km the ECC can only be compared with the two lidars and there are some significant differences. Some of these difference can be explained by the higher spatial resolution of the sonde and the fact that it can react better to small scale ozone fluctuations but from 15 km down to 10 km the differences steadily increase and are more difficult to explain, especially as the two lidars agree well with each other in this region.

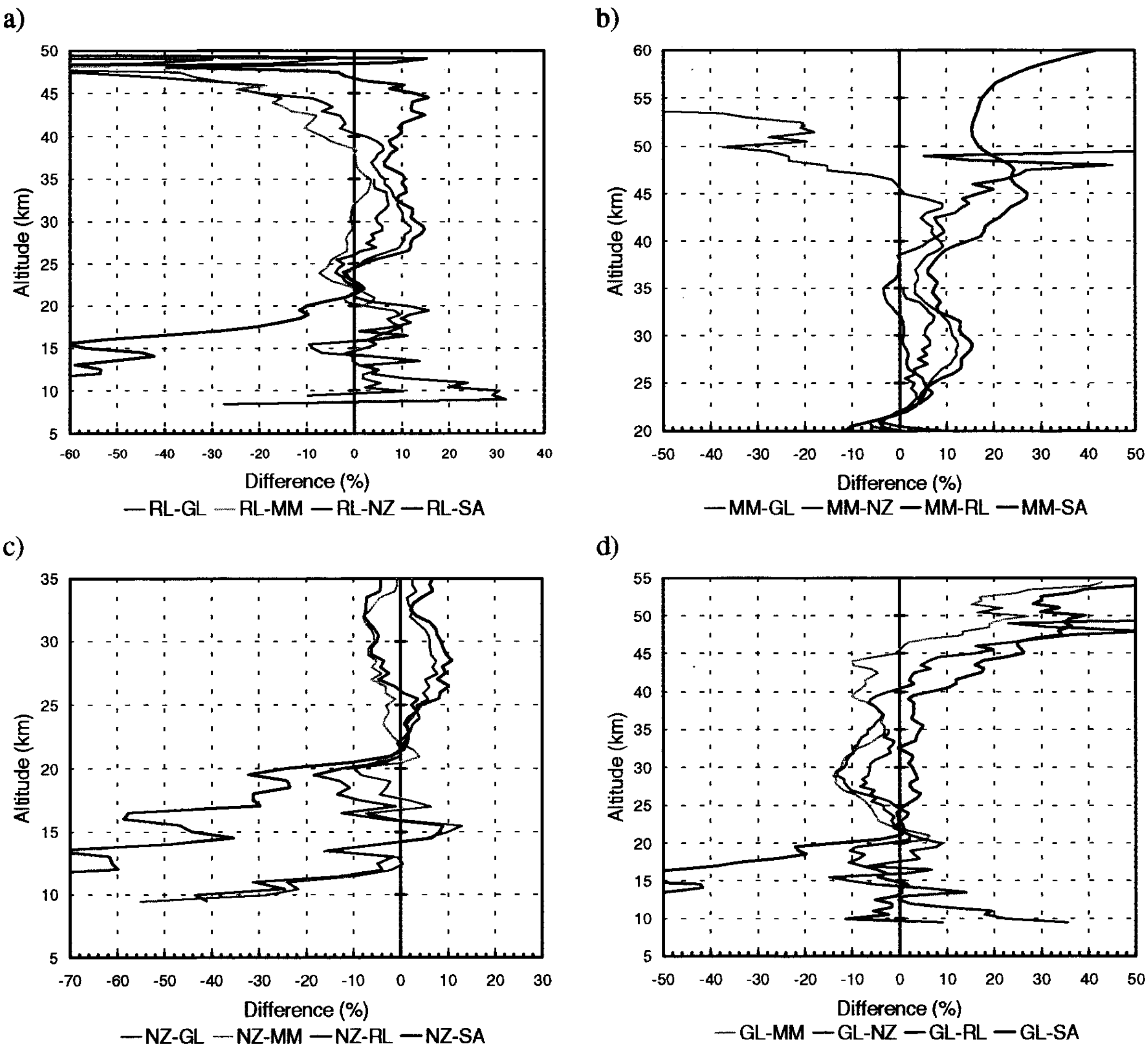

Plate 6. Differences between the blind mean profile for each instrument and all other blind mean profiles, a) (RL-X)/RL, b) (MM-X)/MM, c) (NZ-X)/NZ, d) (GL-X)/GL.

The mean profiles compared here are derived from all of the measurements made by each instrument during the campaign period. However, not all instruments made measurements on all of the same days and if there was significant atmospheric variability during this period this could introduce some biases into the difference calculations. Another way to make these intercomparisons would be to create multiple matching averages, i.e., for any pair of instruments to average only the results from the days when both had measurements and then compare these profiles. This approach has not been taken here as it would increase the number of figures fourfold but this method is being pursued by the RIVM group [*Swart et al.*, 199**] and will be published elsewhere. Indications from this alternative approach are that the differences are reduced slightly but not dramatically.

Single Profiles

There were only two days during the campaign when all the instruments at Lauder and SAGE II made a measurement: 4/20/95 and 4/21/95. On these two days the latitude of the SAGE II measurement was 2.25° north of Lauder on 4/20 and 4.15° north on 4/21. The individual profiles for each of these days are shown in plates 7 and 8.

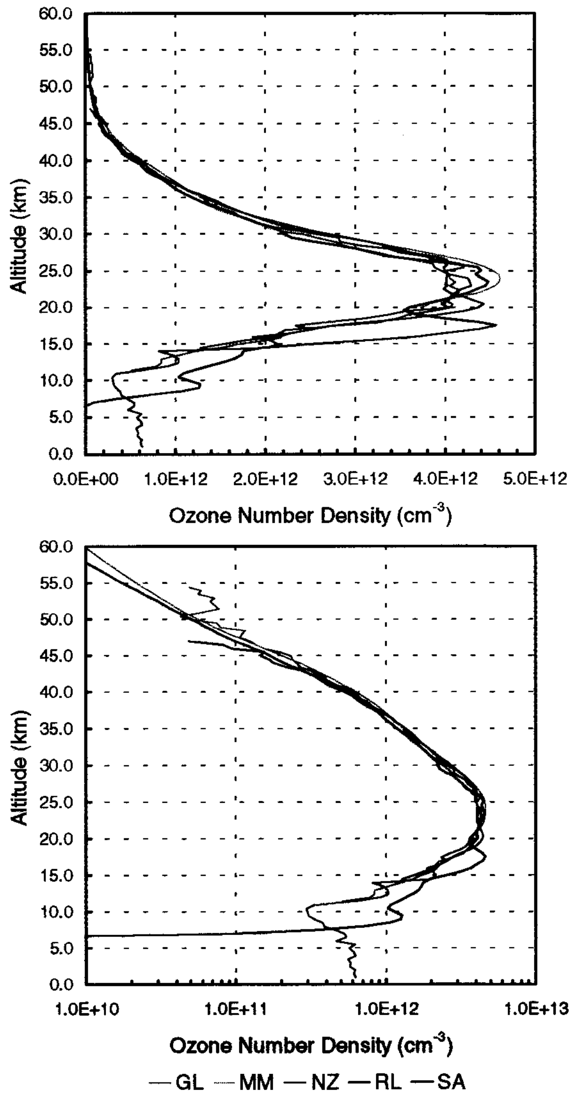

Plate 7. Individual blind ozone profiles for 4/20/95.

Plate 7 shows the profiles obtained on 4/20/95. On this night the SAGE II satellite made a sunset, 06:34 UT, measurement at a tangent point of 47.3°S, some 905 km from the Lauder site. The ECC sonde was launched at 12:28 and made measurements up to its burst altitude of 34.8 km which it reached at 14:13. The GSFC lidar operated from 13:10 to 14:33, followed by the RIVM lidar at 15:12 until 17:50. The microwave instrument obtained a profile from an integration through most of the night, from 13:59 to 17:55.

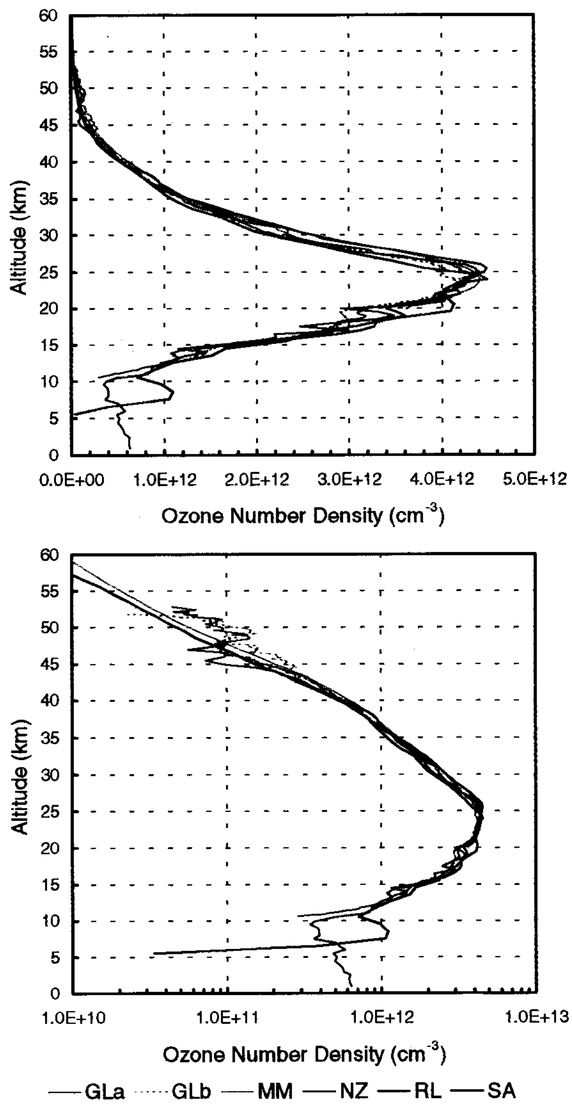

Plate 8. Individual blind ozone profiles for 4/21/95.

Plate 8 shows the results from 4/21/95 when the SAGE II measurement was at 05:03 (sunset) at 49.2°S and 898 km from Lauder. The ECC sonde was launched at 10:11 and burst at 12:07 at 34.8 km altitude. The GSFC lidar made two experiments this night from 08:20 to 09:43 and from 11:35 to 12:56. However, the atmospheric conditions during the later measurement were not good. The RIVM lidar operated in the interval between the two GSFC measurements but was suspended several times during this period because of clouds. The microwave radiometer operated through the night from 08:17 to 13:45. Thus, with the exception of the SAGE II measurements, all of the measurements were made very close together in time as well as from the same location. On 4/20 all of the measurements were made within a 11.5 hour window and on 4/21 they were all made within 8 hours or 5.5 hours and 4.5 hours respectively if the SAGE II measurement is omitted.

Plates 7 and 8 illustrate the level of variability observed for single profiles on a day-to-day basis. Compared to the mean profiles shown in plate 3, these profiles show many small scale perturbations. Some of these are obviously real atmospheric features. For example, in plate 8 there is a layer with lower ozone values just below 20 km altitude that is only about 1 km wide and which was observed by both lidars and the sonde. As has been observed in other intercomparisons, e.g., STOIC [*Margitan et al.*, 1995], the variability appears to be greatest near the ozone peak.

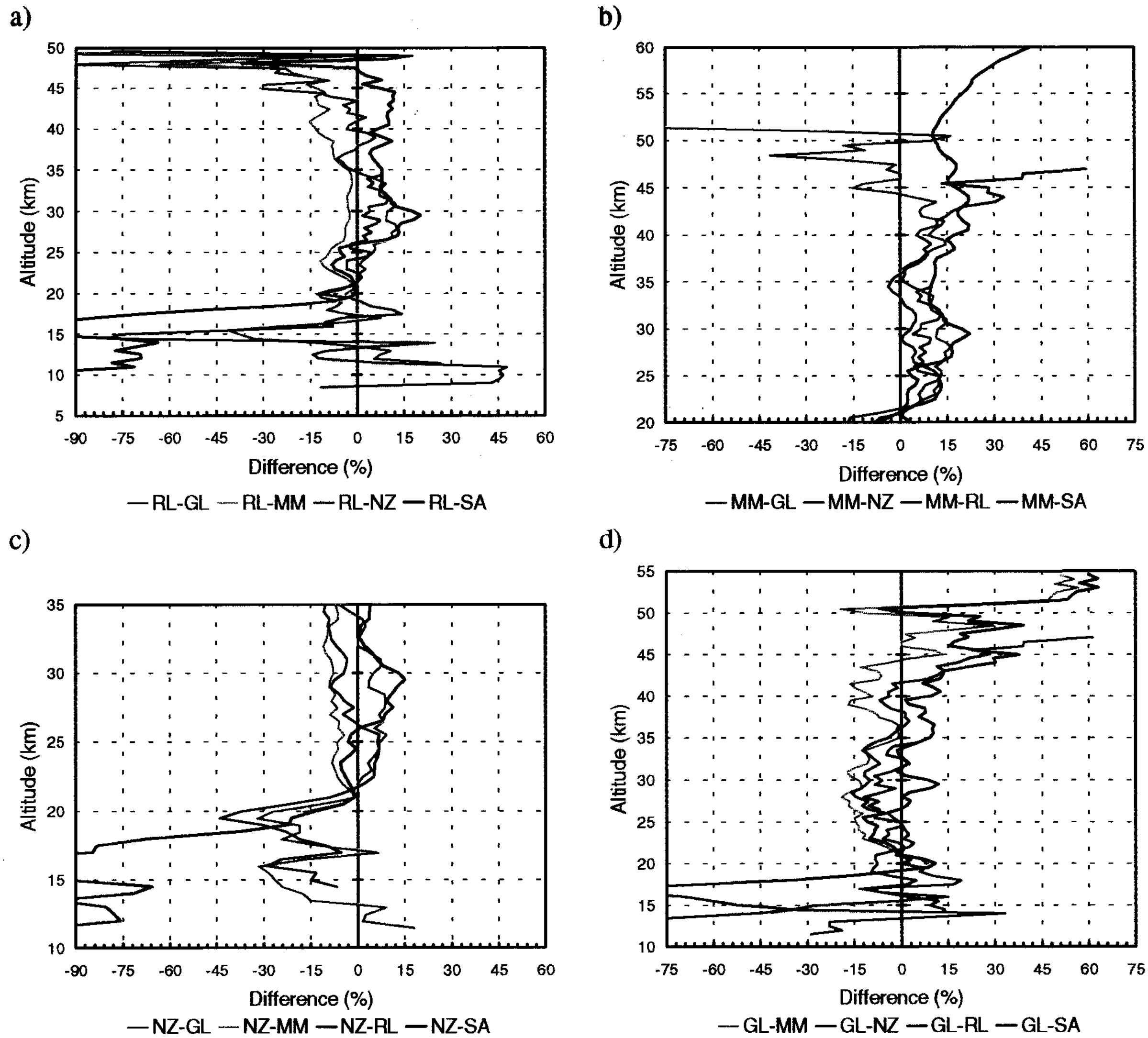

Plate 9. Difference between the blind profile for each instrument and all other blind profiles for 4/20/95, a) (RL-X)/RL, b) (MM-X)/MM, c) (NZ-X)/NZ, d) (GL-X)/GL.

Since the SAGE II measurement was closer, and the local weather conditions at Lauder were better, the results from 4/20/95 were chosen to show detailed examples of the intercomparisons of single profiles. Similar to plate 6 for the OPAL blind average profiles, plate 9 shows the difference of the 4/20/95 blind profile for each individual instrument compared with that from each of the other instruments. As would be expected, these results show the same trends as the campaign average comparisons but the magnitude of the differences is higher, by about 50%.

4. Conclusions

The region of best agreement between all instruments, including SAGE II, is from 20-40 km altitude. In this region single profile measurements agree to ~15% and the campaign average profiles agree to ~10%. Systematic biases in this region are small although the microwave radiometer results tend to have the highest ozone values and the GSFC lidar the lowest. Below 20 km, and down to 10 km, the two lidars agree with each other in the same way as in the 20-40 km region. However, the agreement between the lidars and the ECC sonde is not so good with differences reaching up to 50% at 10 km. There are no microwave results in this region and it is assumed that SAGE II must have observed a totally different airmass below 20 km since there was essentially no similarity in this region between the SAGE II measurements and the measurements at Lauder. At the upper end of the profiles the lidar errors start to increase rapidly, at ~45 km for the GSFC lidar and 40 km for RIVM, and the differences between the lidars, and the microwave and SAGE II increase similarly.

Following the blind campaign all participants had the opportunity to re-evaluate their instruments and analyses and to submit revised results for a new intercomparison. Since the analysis algorithm for the RIVM lidar was in an early stage of development it was expected that revised and improved results would be forthcoming from this group. As it happened, all of the groups operating at Lauder submitted revised results. An intercomparison of the new results is presented in a companion paper [*McDermid et al.*, 1998, Part II, This issue?]

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